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Application Research on the Use of Multiple Comparison Methods in The Evaluation of the Effectiveness of Total Nitrogen and Total Phosphorus Reduction Measures

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Abstract: With the problem of water pollution becoming increasingly serious, excessive discharge of nitrogen and phosphorus has become a key factor affecting water quality and ecological balance. In order to evaluate the effectiveness of different pollution reduction measures in total nitrogen and total phosphorus control, this study evaluates multiple best management practices (BMPs) using multiple comparison methods, in particular Tukey HSD testing. The results of the statistical analysis of the reduction effects of the different measures showed that all the treatment groups with measures were significantly better than the control group without measures. In particular, BMP 8, BMP 7 and BMP 6 showed the best reduction effects. This study not only provides a scientific basis for pollution control decisions, but also lays the foundation for follow-up research, highlighting the importance of multiple comparison methods in environmental science.

Keywords: Multiple comparison methods; Tukey HSD test; Total nitrogen; Total phosphorus; Pollution control.

1. Introduction

With the increasingly serious problem of environmental pollution, the accumulation of pollutants such as nitrogen and phosphorus in water bodies has become one of the important causes of ecosystem degradation. Excessive discharge of these pollutants can lead to eutrophication of water bodies, which in turn can trigger a series of ecological problems such as algal blooms and fish kills. Therefore, controlling the discharge of nitrogen and phosphorus has become one of the priorities of environmental governance worldwide. In the actual governance process, many reduction measures targeting nitrogen and phosphorus pollution have been widely used, such as best management practices (BMPs). However, the effectiveness of different reduction measures may vary significantly under different environmental conditions [1]. Therefore, how to scientifically and effectively evaluate the reduction effect of these measures has become an important issue in water quality management.

In order to compare the effectiveness of different reduction measures in terms of total nitrogen and total phosphorus reduction, traditional statistical analysis methods such as analysis of variance (ANOVA) have been widely used. ANOVA can detect whether there is an overall difference between multiple treatment groups, but it cannot directly identify which specific treatment groups have significant differences. To address this problem, multiple comparison methods have been developed and have become one of the key tools in statistical analysis. In this context, Tukey HSD (Honestly Significant Difference) test, a commonly used multiple comparison method, has been widely used in environmental science research, especially when evaluating the differential effects of multiple reduction measures [2]. The core idea of Tukey HSD test is to determine which measures have significant differences in effect by comparing the mean differences between each pair of measures, thereby helping researchers identify the most effective pollution reduction strategies.

In this study, we combined the Tukey HSD test with other multiple comparison methods to evaluate the reduction effects of various reduction measures on total nitrogen and total phosphorus. By statistically analysing the reduction of total nitrogen and total phosphorus and using the Python function pairwise_tukeyhsd, we obtained a detailed comparison of the reduction effects of different measures [3]. This study not only provides a scientific basis for pollution control decision-makers, but also serves as a reference for future research. Specifically, we identified the measures with the most significant reduction effects through the results of the Tukey HSD test, and further discussed their practical application value in pollution control.

2. Related Work

The application of multiple comparison methods in the evaluation of the effectiveness of total nitrogen and total phosphorus reduction measures is an important area of work in environmental science. It helps decision-makers choose the most effective pollution control measures by quantitatively evaluating the effectiveness of different pollution reduction measures. In this study, the Tukey HSD (Honestly Significant Difference) test, a commonly used multiple comparison method, played a key role. The core idea of the Tukey HSD test is to compare the mean differences of each pair of treatment combinations and determine whether these differences are statistically significant by calculating the smallest significant difference (HSD) [4].

Results of the analysis of total nitrogen reduction in the study showed that all treatment measures (BMP1 to BMP8) had a significant reduction effect compared to the control group (BMP0), especially BMP8, BMP7 and BMP6, which had the most significant reduction effect. This means that these measures performed well in reducing total nitrogen and were significantly better than the other measures. Similarly, in the analysis of total phosphorus reduction, BMP8 also

showed the strongest reduction effect, indicating that it also has a significant advantage in reducing total phosphorus pollution.

These results were calculated and verified using Python's pairwise_tukeyhsd function, which further demonstrates the value of Tukey HSD testing in multiple comparisons [5]. The visual charts of the research results (Figures 1 and 2) intuitively demonstrate the differences in the effectiveness of different measures in reducing total nitrogen and total phosphorus, helping researchers and decision-makers quickly identify the best pollution control measures. This study not only highlights the importance of multiple comparison methods in data analysis, but also the need to evaluate environmental pollution control measures using scientific methods. Through this systematic analysis, researchers can more accurately evaluate the effectiveness of each measure, thereby providing a scientific basis for environmental protection and pollution control [6].

In short, the application of multiple comparison methods in the evaluation of the effectiveness of total nitrogen and total phosphorus reduction measures not only provides a quantitative basis for specific pollution control measures, but also provides valuable experience and methods for environmental science research and practical applications. The application of this research method has promoted the scientific development of pollution control technology and is of great significance for achieving the goal of more efficient environmental protection.

3. Model Building and Solving

The core idea of the Tukey HSD test is to compare the mean difference of each pair of combinations and calculate a 'least significant difference' (HSD). If the mean difference between the two groups is greater than this HSD value, then we can consider the difference between the two groups to be statistically significant. The HSD value is calculated as follows:

$$HSD = q * \sqrt{\frac{MSW}{n}} \quad (1)$$

Where q is based on the total nitrogen and total phosphorus reductions after treatment. MSW—ANOVA calculates the mean square within the group. n is the number of samples in each group (assuming equal sample sizes in each group) [7]. Tukey HSD tests or other multiple comparison methods are further used to determine which specific measures have significant differences. This helps to identify which measures perform best in terms of total nitrogen or total phosphorus reduction, and which measures are relatively ineffective. Using Python's pairwise_tukeyhsd function, and bringing in the already processed total nitrogen reduction data, the nitrogen solution results can be seen in Table 1.

Table 1. Total nitrogen reduction

Group1	Group2	Meaddiff	p-adj	Lower	Upper	Reject
BMP0	BMP1	-7.6245	0.0	-8.842	-6.407	True
BMP0	BMP2	-6.3581	0.0	-7.5756	-5.1406	True
BMP0	BMP3	-8.0076	0.0	-9.2251	-6.7901	True
BMP0	BMP4	-5.0993	0.0	-6.3168	-3.8818	True
BMP0	BMP5	-3.8006	0.0	-5.0181	-2.5831	True
BMP0	BMP6	-10.1502	0.0	-11.3676	-8.9327	True
BMP0	BMP7	-13.986	0.0	-15.2035	-12.7686	True
BMP0	BMP8	-17.0482	0.0	-18.2656	-15.8307	True

The results of the tests in Table 1 show a comparison of the effectiveness of different measures (BMPs) in reducing total nitrogen or total phosphorus. Each row shows the results of a comparison between two different measures.

The Group1 and Group2 columns indicate the two groups of measures being compared. The Meandiff column shows the average difference in total phosphorus reduction between the two groups. A positive number indicates that the first group is more effective than the second, while a negative number indicates the opposite. The p-adj column provides the adjusted p-value, which takes into account the effect of multiple comparisons. A p-value less than 0.05 generally indicates a statistically significant difference [8]. The Lower and Upper columns show the 95% confidence interval for the mean difference. If this interval does not contain 0, it generally indicates a significant difference between the two groups [9]. The Reject column indicates whether the null hypothesis (i.e. the hypothesis that there is no difference between the two measures) is rejected. If it is true, it means that statistically there is a significant difference between the two groups.

BMP0 is significantly different from all other measures (BMP1 to BMP8), with BMP8, BMP7 and BMP6 having the most significant effect relative to BMP0. This shows that all other measures can significantly reduce pollution compared to the situation where no measures are taken (BMP0).

As shown in Figure 1, among the total nitrogen reductions, BMP8 measures resulted in the largest average reduction, followed by BMP7, BMP6, BMP3, BMP1, BMP5, BMP4, and BMP2, among which BMP2 resulted in the smallest average reduction [10].

By using Python's pairwise_tukeyhsd function and bringing in the data on total phosphorus reductions that have already been processed, the phosphorus solution can be obtained as shown in Table 2:

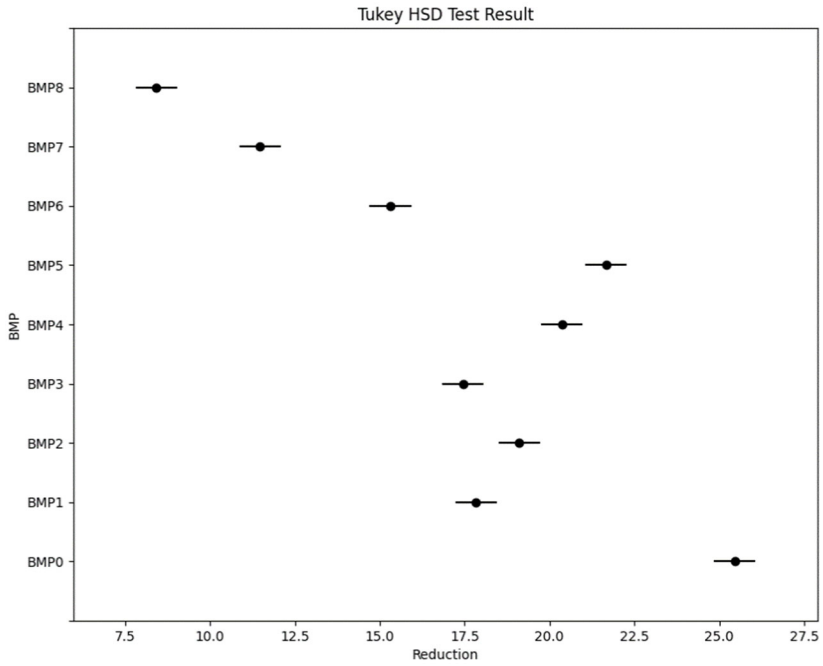

Figure 1. Tukey HSD test results for nitrogen

Table 2. Total phosphorus reduction

Group1	Group2	Meaddiff	p-adj	Lower	Upper	Reject
BMP0	BMP1	-4.7299	0.0	-5.4578	-4.0020	True
BMP0	BMP2	-3.7632	0.0	-4.4911	-3.0353	True
BMP0	BMP3	-4.7812	0.0	-5.5092	-4.0533	True
BMP0	BMP4	-4.0878	0.0	-4.8158	-3.3599	True
BMP0	BMP5	-4.4552	0.0	-5.1831	-3.7273	True
BMP0	BMP6	-7.0890	0.0	-7.8169	-6.3611	True
BMP0	BMP7	-8.2941	0.0	-9.0220	-7.5662	True
BMP0	BMP8	-9.6870	0.0	-10.415	-8.9591	True

Table 2 shows the results of the comparison of the different measures (BMP0 to BMP8) in terms of their effectiveness in reducing total phosphorus. All measures reject BMP0 (no measures taken), which means that all measures significantly improve the effectiveness of total phosphorus reduction compared to no measures being taken [11]. BMP8, in particular, shows the strongest reduction effect, as it improves the reduction the most (meandiff is -9.687). There are significant differences between some measures, such as BMP1 and BMP6, BMP1 and BMP7, and BMP1 and BMP8, which all show significant differences (reject is True). This shows that some measures are more effective than others in terms of total phosphorus reduction.

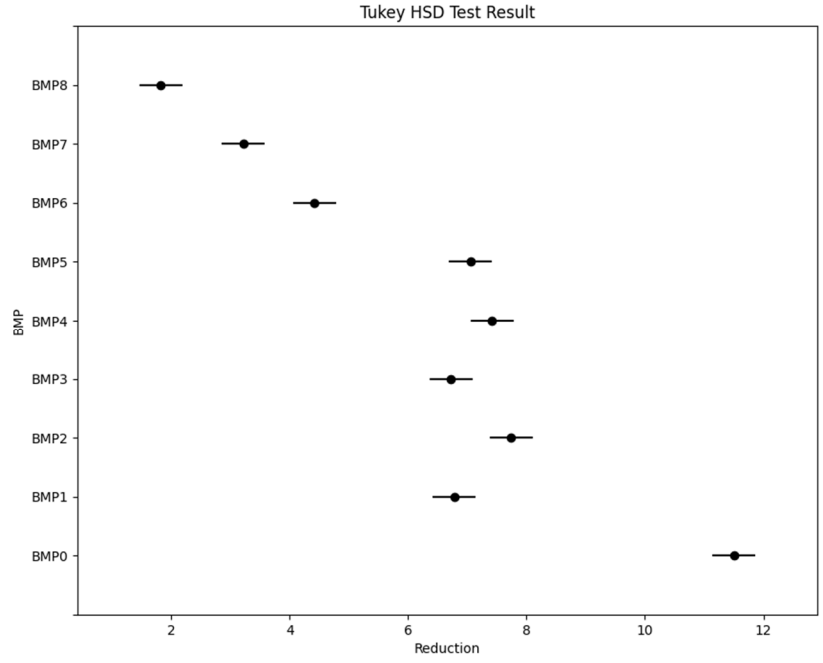

Figure 2. Tukey HSD test results for phosphorus

As shown in Figure 2, among the total nitrogen reductions, BMP 8 measures resulted in the largest average reduction, followed by BMP 7, BMP 6, BMP 3, BMP 1, BMP 5, BMP 4, and BMP 2, among which BMP 2 resulted in the smallest average reduction. This is because in the context of environmental science and pollution control, the reduction value usually refers to the reduction in pollutant load or concentration after a measure is taken. Therefore, the more 'small' (in fact, the greater the negative value), the more effective the measure.

4. Discussion

The application of multiple comparison methods is particularly important in the evaluation of the effectiveness of measures to reduce total nitrogen and total phosphorus, especially in the field of environmental science. With the aggravation of water pollution, excessive emissions of nitrogen and phosphorus have become the main factors affecting water quality and ecological balance. In order to effectively control the discharge of these pollutants, it is necessary to adopt different best management practices (BMPs) for treatment. However, the differences in the effectiveness of different measures under different conditions make the scientific evaluation of these measures a difficult task.

Analysis of variance (ANOVA) can determine whether there is a significant difference overall, but it cannot indicate which specific measures differ. Therefore, the application of multiple comparison methods, such as the Tukey HSD test, has become an important tool for evaluating the effectiveness of measures. The Tukey HSD test can identify which measures have a significant effect on reducing total nitrogen and total phosphorus by comparing the mean difference of each pair of measures and calculating the smallest significant difference (HSD). This method not only improves the accuracy of the statistical analysis, but also provides a reliable basis for researchers to determine the best pollution control strategy.

In practical applications, by analysing the data on nitrogen and phosphorus reduction after treatment, researchers can clearly identify the relative effectiveness of each measure. For example, the results show that most BMP measures significantly reduce total nitrogen and total phosphorus concentrations compared to the control group (no measures taken), especially some measures such as BMP8, BMP7 and BMP6. These results not only provide clear guidance for decision-makers in selecting the most effective strategies, but also lay the foundation for future research.

In addition, the visualisation of the results of multiple comparison methods not only makes the data easier to understand, but also enhances the transparency and credibility of the research. Decision-makers can quickly identify the optimal measures through these intuitive data displays, so as to efficiently formulate governance plans. The application of this method is not limited to the current study, but can also be extended to other environmental governance fields, promoting the wide application of scientific methods in environmental management.

In summary, the application of multiple comparison methods in the evaluation of the effectiveness of total nitrogen and total phosphorus reduction measures provides quantitative analysis results and provides a scientific basis for pollution control. The effectiveness and practicality of this method not only improves the quality of environmental science research, but also makes an important contribution to achieving the goal of more efficient environmental protection. In the future, further exploration and improvement of multiple comparison methods will help to improve the scientific nature and accuracy of environmental governance and promote the achievement of sustainable development.

5. Conclusion

In this study, we have explored the multiple comparison method in depth, with a particular focus on the Tukey HSD test, and its application to the evaluation of the effectiveness of measures to reduce total nitrogen and total phosphorus. Through scientific data analysis, we can effectively evaluate the relative effectiveness of different pollution control measures, providing important support for decision-making in water body management. The results showed that most best management practices (BMPs) significantly improved the total nitrogen and total phosphorus reduction effects compared to the control group without measures, especially BMP8, BMP7 and BMP6. This finding not only provides a clear direction for decision-makers, but also lays a good foundation for follow-up research.

The application of multiple comparison methods allowed us to go beyond the limitations of traditional analysis of variance and specifically identify significant differences between measures, thereby statistically confirming the most effective reduction strategies. The Tukey HSD test ensured the scientific accuracy of our selection of pollution control measures by comparing the differences in the means of each group. Especially in the field of environmental science, it is crucial to effectively control nitrogen and phosphorus emissions in the face of complex ecological problems. Therefore, the effective application of this method greatly enhances the reliability and transparency of the research, allowing decision-makers to quickly identify the optimal governance plan.

The results of this study not only provide a quantitative basis for environmental governance, but also highlight the necessity and importance of scientific methods in environmental management. By accurately assessing the effectiveness of total nitrogen and total phosphorus reduction, we hope to promote the scientific development of pollution control technology and more efficient environmental protection. Future research could further explore the application of other multiple comparison methods to provide more tools and perspectives for environmental governance and achieve the goal of sustainable development.

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